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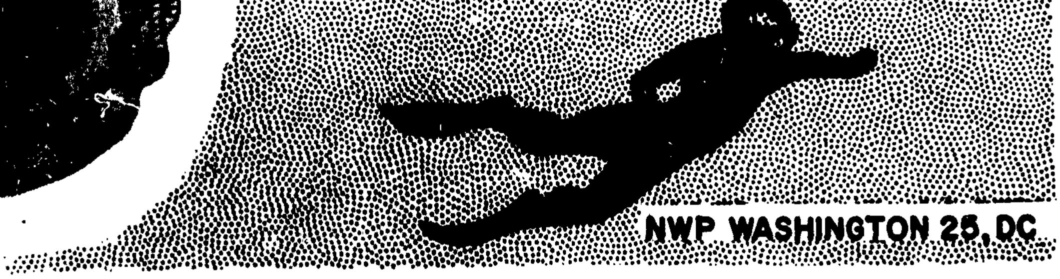
Experimental Diving Unit



U. S. NAVY EXPERIMENTAL DIVING UNIT
U. S. NAVAL STATION
(WASHINGTON NAVY YARD ANNEX)
WASHINGTON 25, D. C.

RESEARCH REPORT 2-63

CONSTITUTIONAL FACTORS IN DECOMPRESSION SICKNESS

PROJECT F 011-06-01 Task 3361, Test 3

by
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26 April 1963

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ABSTRACT

589 divers who had never incurred decompression sickness were compared with 414 treated cases of decompression sickness to determine if there were any differences of sufficient magnitude to be employed as selection criteria. Among the factors explored (age, height, weight, and body type), no useful differences between the groups could be found.

SUMMARY

PROBLEM:

To enable selection of bends-resistant men for diving duty, the feasibility of employing constitutional factors as selection criteria was investigated. Feasibility was determined by ascertaining if there was a relationship between constitutional factors (age, height, weight, and body build) and the incidence of decompression sickness. A second problem was to determine if the depth of a dive and body type interact to influence the probability of contracting bends.

METHOD:

Groups of divers who had reported an incidence of bends were compared, in terms of mean differences on each of the variables, with another group of divers who had never incurred bends. The second problem, the relationship between depth of dive and body type on the incidence of bends, was measured by an eta coefficient of curvilinear relationships.

FINDINGS:

None of the obtained mean differences between the divers incurring bends and those who did not were of sufficient magnitude to distinguish between the groups. Therefore, no selection criteria could be established.

An eta correlation coefficient failed to reach significance. Consequently, it was concluded that body type and depth of dive do not interact.

The findings suggest that the role of adipose tissue in the etiology of decompression sickness is not as great as has been thought.

RECOMMENDATIONS:

1. Further research should be performed within a laboratory setting where greater control could be exercised, and, consequently, where more definite results could be obtained.

2. In addition to the factors employed in this report, future investigations of bends-resistance should include specific gravity and indicators of tissue perfusion efficiency.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Ships, Navy Department Research Project F011-06-01, Task 3361, Test 3.

Abstracting the Diving Casualty Data Cards was begun on 1 July 1962 and was completed 1 September 1962. Statistical analysis of the abstracted data and the data submitted by all diving units was initiated 15 September 1962 and completed 15 December 1962. The final manuscript was completed on 1 April 1963.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of Ensigns R. E. KEEFE, Jr., K. R. HANSEN, G. G. HAZOURI, and R. B. JOHNSON in analyzing the data during their research clerkships at the Experimental Diving Unit. Special thanks are due to Commander R. D. WORKMAN who provided an immeasurable amount of guidance in writing the manuscript.

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1. INTRODUCTION

1.1 Background

1.1.1 When new decompression schedules are developed, several subjects are employed for testing each dive. Frequently, only one member of a pair of subjects on the same dive contracts decompression sickness. The failure to resist decompression sickness in situations such as this is usually attributed to individual susceptibility.

1.1.2 Studies attacking the phenomenon of aviation bends[1] have found that a number of constitutional factors are associated with resistance to aviation bends. The influence of these factors in decompression sickness, however, has been studied very little. If a measurable interaction between constitutional factors and decompression sickness exists, constitutional variables could be employed to select a group of men resistant to decompression sickness for diving duty. By selecting less susceptible divers, the non-productive time required for decompression in the present decompression schedules could be lessened. The present report is an attempt to explore the possibilities of a relationship between the incidence of decompression sickness following exposures to hyperbaric pressure and the constitutional factors of age, height, weight, and body build.

1.2 Constitutional factors and susceptibility

1.2.1 Decompression sickness can result whenever there is an impairment of the effusion of inert gas from the body tissues. Since blood is the carrier of gas, poor blood circulation can drastically hinder the elimination of excess gas from the tissues (26). Hence, age, because of the decreased efficacy of the circulation system concomitant with aging, has been considered an important factor in decompression sickness (11). A strong relationship between age and susceptibility to aviation bends has been demonstrated by numerous correlational studies (6,11,13,25). Gray (11) compiled all available data and determined a composite correlation of 0.87 between age and susceptibility, as measured by the frequency of occurrence of aviation bends after repeated exposures to altitude.

1.2.2 Based on in vitro studies, the amount of adipose tissue is another important factor in gas exchange (1,3,6,14,21). Nitrogen is more soluble in fat than in other tissues and, in addition, adipose tissue usually has a poor vascular bed. Thus, although fat is capable of retaining large quantities of dissolved inert gas, once the gas is accumulated, the typically poor blood supply of fat hampers gas elimination (5,10,14). This suggests that obese men should be more prone to bends due to the difficulty of emptying the large potential gas reservoir of their abundant fatty tissues.

1.2.3 The problems associated with estimating body fat within individuals have made confirmation of the in vitro studies by in vivo studies difficult (3,7,19). Several methods, however, have succeeded in indicating greater susceptibility to aviation bends in obese people (4,6,9,12,26,28).

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[1] Throughout this report, aviation bends will refer to the symptoms contracted after exposure to decreased atmospheric pressure. The terms decompression sickness and bends will be employed when the discussion pertains to symptoms appearing after exposure to increased atmospheric pressure.

1.2.4 Height and weight measurements were employed as one of the earlier indicators of body build, especially as an estimate of fat. A relationship between both measures and aviation bends has been reported by Swann (26), but other indices, such as body surface area, yielded improved results. Motley, et al (20) found similar results by employing combined height and weight measurements, but, again, other measures of body type were more efficacious.

1.2.5 Estimates of body build also have been attempted through the use of standard height and weight tables (6). The tables, however, make no distinction betweem persons who exceed the "ideal" weight because of fat and those who are overweight due to a higher ratio of bone and muscle tissue. In an effort to overcome this problem, Behnke (1) used a method, developed by Webster, based on corporeal specific gravity. He found that subjects with a low specific gravity, or a relatively high degree of adipose tissue, were more susceptible to decompression sickness than those with a higher specific gravity. Behnke's results were based, however, on a very small sample.

1.2.6 Corporeal specific gravity has been employed also by Fraser (9) and Welham, et al (28) in studies of aviation bends. Fraser found a significant relationship (correlation coefficient of 0.30) while Welham's study did not. Welham attributed his insignificant findings to a sample that was restricted in range. The subjects were all qualified divers, and, therefore, Welham concluded that the insignificant findings were evidence that these divers were resistant to bends.

1.2.7 Although specific gravity is apparently capable of differentiating between persons susceptible to aviation bends and those who are not, the technique of measurement is difficult and cumbersome. Much more convenient indices of body build are linear density, (wt/ht) and the ponderal index (wt/ht^3). Swann and Rosenthal (26) found a significant relationship between susceptibility and linear density and Gray (11) successfully assessed susceptibility to aviation bends utilizing the ponderal index.

1.2.8 The most elaborate studies of body type have been those of Sheldon (24,25) in determining the relationship between body type, disease, and personality. Sheldon developed a systematic method of describing body type in terms of three components--endomorphy (round-soft), mesomorphy (square-muscular), and ectomorphy (long-thin). An individuals's body type, or somatotype in Sheldon's terminology, is the amount of each of these components rated on a seven point scale, where one is the least and seven is the greatest expression of the component found in normal population. Each individual, of course, is a composite of all components and, therefore, he is given a rating on each one.

1.2.9 Dupertuis, et al (7) compared Sheldon's somatotyping procedures with corporeal specific gravity to determine if somatotype ratings could be used to express the degree of fat within individuals as accurately as specific gravity. Dupertuis divided his subjects into three groups of low, medium, and high specific gravity to correspond with the ectomorph, mesomorph, and endomorph somatotypes. Somatotype ratings which had been performed earlier and independently were then correlated with the specific gravity measurements. A correlation coefficient of -0.85 between the first component, endomorphy or fatness, and the obtained specific gravity was found. The correlations between the other components were lower but highly significant.

1.2.10 The high correlations between somatotype and specific gravity derived by Dupertuis indicate that somatotyping could be used as an indicator of fat content with reasonably good accuracy. In addition,

the somatotype rating provides information about relative amounts of tissues other than fat.

1.2.11 Sheldon has developed a nomograph based on the ratio of $ht/\sqrt[3]{wt}$ which yields approximations to his somatotype ratings. If photographs or clinical observations are made in conjunction with the nomograph, ratings of somatotype can be obtained without resort to the usually required anthropometric measurements. In the present study, neither photographs nor clinical observations were available. Furthermore, since selection procedures should be as simple as possible, it was decided to determine if the $ht/\sqrt[3]{wt}$ ratio, hereafter called the Sheldon index, alone could discern a bends susceptible group.

1.2.12 In interpreting the Sheldon index, a relatively high ratio is associated with leanness and a low ratio with fatness. Thus a short heavy man would have a lower index than a tall, lean man. Based on the results of the aviation bends studies, it would be expected that a group of bends-susceptible divers would have a significantly lower Sheldon index than would a group which was resistant to bends.

1.3 <u>Interaction of depth of dive and body build</u>

1.3.1 From in vitro nitrogen solubility studies of fatty animal tissues, Behnke deduced that the gas reservoir of adipose tissues could absorb and hold much greater quantities of nitrogen during decompression than other tissues. If the time interval of a dive were brief, the fat would not become appreciably saturated due to its low rate of gas exchange (1,14,15). Upon return to lower pressures, other tissues would eliminate gas into the unsaturated fat by the mechanism of diffusion (1,3). Therefore, adipose tissue could act as a buffer to other tissues to prevent the formation of bubbles. As Behnke stated it:

> In the body after short exposures (up to 30 minutes) to high pressure, the fat acts as a nitrogen absorbent during decompression and serves as a buffer against bubble formation in the blood stream. Fat men, consequently, with adequate blood circulation should be better suited for short exposures in compressed air than lean men (2).

1.3.2 The high gas absorption capacity and poor circulation of bone marrow could conceivably be a more serious problem than saturated fatty tissues from long, deep dives (1,3,14). Thus, Behnke states that:

> From the point of view of body economy, the bones constitute the weak organ that renders man unsuited for long exposures in compressed air (2).

One may infer from this, then, that the lean man who has relatively small amount of adipose tissue compared to bone may be predisposed to decompression sickness following long dives. In general, though, Behnke considers the fat man more prone to bends than the lean man (3). Thus, with the exception of either very long or very short dives, the obese individual would be in the most danger.

1.3.3 If one assumes that the depth of dive is as important as time in saturating the tissues, then Behnke's statements can be interpreted as varying degrees of severity of exposure. Thus, if the time intervals of dives are held constant, depth could be varied to manipulate exposure severity. On this basis, Behnke's hypothesis would state that obese

men would be protected from bends following shallow dives, more prone to bends following medium depth dives, and would not incur decompression sickness as often as men having relatively high amounts of bone at deep depths.

1.3.4 This hypothesis can be described by a curvilinear relationship where the probability of contracting decompression sickness is a function of body type and depth of dive.

1.3.5 Sheldon's somatotyping procedure provides a means of empirically testing this hypothesis developed from Behnke by giving an assessment of the relative amounts of various tissues. The lean ectomorph is composed primarily of bone and skin; the mesomorph, muscle; and the endomorph, fat. The problem, then, becomes to evaluate the incidence of decompression sickness among divers of these various body builds at different depths.

1.3.6 In accordance with Behnke's hypothesis, a somatotype rating, or Sheldon index, indicating leanness would be expected more often among divers contracting decompression sickness at the shallow depths. On the other hand, at medium depths, fat men having an endomorphic somatotype or medium Sheldon index would be more likely to encounter difficulties, while at deeper depths, divers who contract bends would more likely be lean men or ectomorphs with a low Sheldon index. The hypothetical curve described by this hypothesis is illustrated in Figure 1. In addition to the investigation of the role of constitutional factors in decompression sickness, the present report attempted to determine if this curve were tenable.

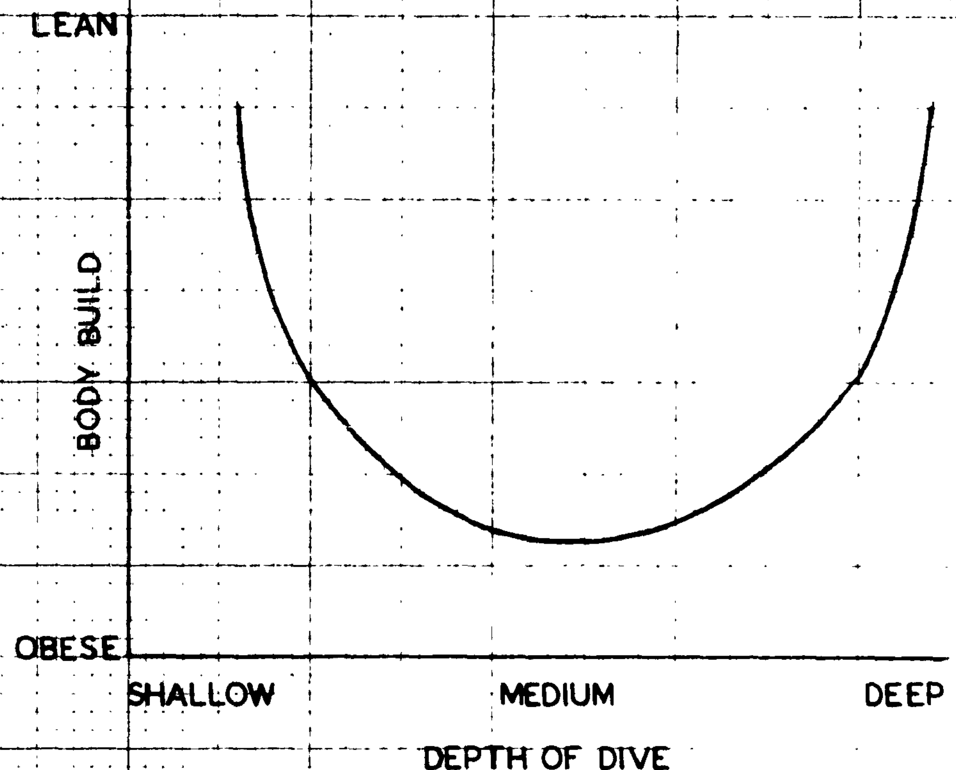
1.4 Objective

1.4.1 This report attempts to find variables which could be used to select divers resistant to decompression sickness. The constitutional factors of age, height, weight, and the Sheldon index, as a measure of fatty tissues, are employed to determine if they are capable of discriminating between divers who have contracted decompression sickness and those who have not.

1.4.2 The effects of the constitutional factors in decompression sickness are hypothesized to be as follows:

1. Divers who have incurred decompression sickness are older than those who have not.
2. Short-heavy divers are more prone to decompression sickness than are tall-lean divers.
3. The body type of divers afflicted with decompression sickness is indicative of higher amounts of fat than divers who have not been afflicted. As measured by the Sheldon index, divers incurring decompression sickness have a lower Sheldon index value than those who have not.

1.4.3 The second objective was the testing of the hypothesis developed from Behnke's work, that the probability of contracting decompression sickness is a function of the type of body build and the depth of the dive. The relationship between body type and depth is curvilinear.



HYPOTHETICAL CURVE INDICATING THE DEPTH OF DIVE WHERE THE PROBABILITY OF AN EPISODE OF DECOMPRESSION SICKNESS IS GREATER FOR VARIOUS BODY TYPES.

FIGURE 1

2. EXPERIMENTAL DESIGN

2.1 Susceptibility

2.1.1 The design assessing individual susceptibility consisted of a statistical comparison of groups of divers who had incurred bends with divers who had not. The groups were compared in terms of mean values computed from reported measurements of each of the variables considered--age, height, weight, and the body build as indicated by the Sheldon index. The mean differences between the groups were submitted to the t-test to determine if they were more probably due to chance variations than actual differences. A .05 level of confidence was required to reject the hypothesis that the difference between the means could have arisen by chance alone.

2.1.2 If discrepancies of sufficient magnitude were found between the group of divers who experienced bends and those who had not had bends, this information was to be used to establish normative data for the selection of incoming diving personnel for initial training.

2.2 Incidence of bends as a function of body type and depth

The joint influence of depth of dive and body type upon the incidence of decompression sickness is, supposedly, a curvilinear relationship (see figure 1). Consequently, an eta correlation ratio for determining the strength of curvilinear relationships was computed rather than the more typical Pearson correlation coefficient for linear relationships.

3. PROCEDURE

3.1 Subjects

3.1.1 A group of divers who had incurred decompression sickness was formed from data compiled by Rivera (23) covering medical histories of cases of decompression sickness treated by the U. S. Navy between 1958 and 1961. The groups included 413 cases, both military and civilian. Among the 413 cases, there were numerous instances in which decompression time following the dive had been compromised or where other elements, such as fatigue, had been considered as major precipitating factors in the onset of decompression sickness. To obtain a group in which individual susceptibility was apparently the only factor, all of the cases in which any possible complications existed were eliminated. This procedure yielded a second group of 128 uncomplicated bends cases. The first group, consisting of all 413 cases of bends was termed the "bends" group. The second group of 127 cases was named the "uncomplicated-bends" group.

3.1.2 A control group of subjects was obtained by requesting vital statistics on divers who had never incurred decompression sickness from all U. S. Navy diving activities except the Underwater Demolition Units and Explosive Ordnance Disposal Units. Because the mission of the UDU and EODU involves very few dives which are of sufficient depth and duration to produce bends, they were excluded from the study. The diving activities were asked not to include any diver who had experienced even a slight case of decompression sickness at any time. The total number of subjects submitted by the diving activities was 589. This control group was termed the "no-bends" group.

3.1.3 Subjects for the correlational analysis were selected from the bends-uncomplicated group. The subjects were placed into eight groups depending upon the depth of the dive during which decompression sickness occurred. The depths were 90, 150, 180, 210, 240, 270, and 300 feet. To conform to Behnke's hypothesis, the time of the dive was held constant by excluding all cases where bottom time was greater than 30 minutes. The total number of subjects which could be extracted from the original bends-uncomplicated group to meet these requirements of the design was 89. These 89 subjects were unevenly distributed in the groups of eight depths. The number of subjects for each of the eight groups varied from 4 to 25.

3.2 Estimates of body build

3.2.1 To indicate "leanness" or "fatness" of body build, a Sheldon index was determined for each subject from a nomograph developed by Sheldon (25).

3.2.2 To ascertain if the Sheldon index could effectively approximate specific gravity, a rank order correlation coefficient between the Sheldon index and specific gravity measures was computed by the author from published data of Behnke (4) and unpublished data of Kyle (17) for a total of 30 subjects. A value of .637 ($p < .01$) was found which indicates that the Sheldon index should be adequate for assessing the amount of fatty tissue.

4. RESULTS

4.1 Age

A mean age of 30.80 years with a standard deviation of 7.40 was obtained from the no-bends control group. Means of 30.65 and 30.85 with standard deviations of 5.90 and 5.60 were found for the bends and bends-uncomplicated groups, respectively. The t-test demonstrated that there were no significant differences between the means. These results are presented in Table 1.

TABLE 1

MEAN AGE IN YEARS OF THE NO-BENDS, BENDS AND BENDS-UNCOMPLICATED GROUPS

	No Bends	Bends	Bends-Uncomplicated
N	589	414	128
M	30.80	30.65	30.85
SD	7.40	5.90	5.60
SE	0.31	0.29	0.50
"t" between means		.83	.14

4.2 Weight

The mean difference between the groups when weight was used as the criterion also failed to reach significance when subjected to a t-test. A mean of 170.79 pounds was found for the no-bends group, one of 170.89 for the bends group, and one of 172.25 for the bends-uncomplicated group. The standard deviation of the no-bends group was 22.86, while a standard

deviation of 19.32 was found for the bends group and one of 15.00 for the bends-uncomplicated group. The means and standard deviations of the groups' weights are presented in Table 2.

TABLE 2

MEAN WEIGHT IN POUNDS OF THE NO-BENDS, BENDS, AND BENDS-UNCOMPLICATED GROUPS

	No Bends	Bends	Bends-Uncomplicated
N	413	590	128
M	170.79	170.89	172.25
SD	22.86	19.32	15.00
SE	1.12	0.79	1.33
"t" between means	0.07	0.84	

4.3 Height

The mean difference between the height values of the groups could have occurred by chance as indicated by the t-test. Mean values of 70.07, 69.92, 70.55 inches were found for the no-bends, bends, and bends-uncomplicated groups, respectively. These results, with appropriate standard deviations, appear in Table 3.

TABLE 3

MEAN HEIGHT IN INCHES OF THE NO-BENDS, BENDS AND BENDS-UNCOMPLICATED GROUPS

	No Bends	Bends	Bends-Uncomplicated
N	589	413	128
M	70.07	69.92	70.15
SD	2.61	2.91	3.00
SE	0.11	0.14	0.27
"t" between means	.83	.29	

4.4 Sheldon Index

4.4.1 A t-value of 2.50 was obtained between the mean of the no-bends group of 12.65 and the mean of the bends group of 12.58. The t-value is significant beyond the 1% level of confidence which means that the difference between the two groups could have occurred by chance alone in only 1 out of 100 cases. The respective standard deviations were 0.40 and 0.45 for the no-bends and bends group.

4.4.2 The difference between the no-bends group and the uncomplicated-bends group on the Sheldon index was not significant. A Sheldon index mean of 12.66 was computed for the uncomplicated-bends group, which is very similar to the aforementioned mean of 12.65 for the no-bends group. The results of the analysis of the Sheldon index values appear in Table 4.

TABLE 4

MEAN VALUES OF THE SHELDON INDEX OF NO-BENDS, BENDS, AND BENDS-UNCOMPLICATED GROUPS

	No Bends	Bends	Bends-Uncomplicated
N	589	414	128
M	12.65	12.58	12.66
SD	0.40	0.45	.40
SE	0.016	0.022	0.035
"t" between means	*2.50		.29

* Signif. beyond .01 level of confidence

4.5 Body type and depth

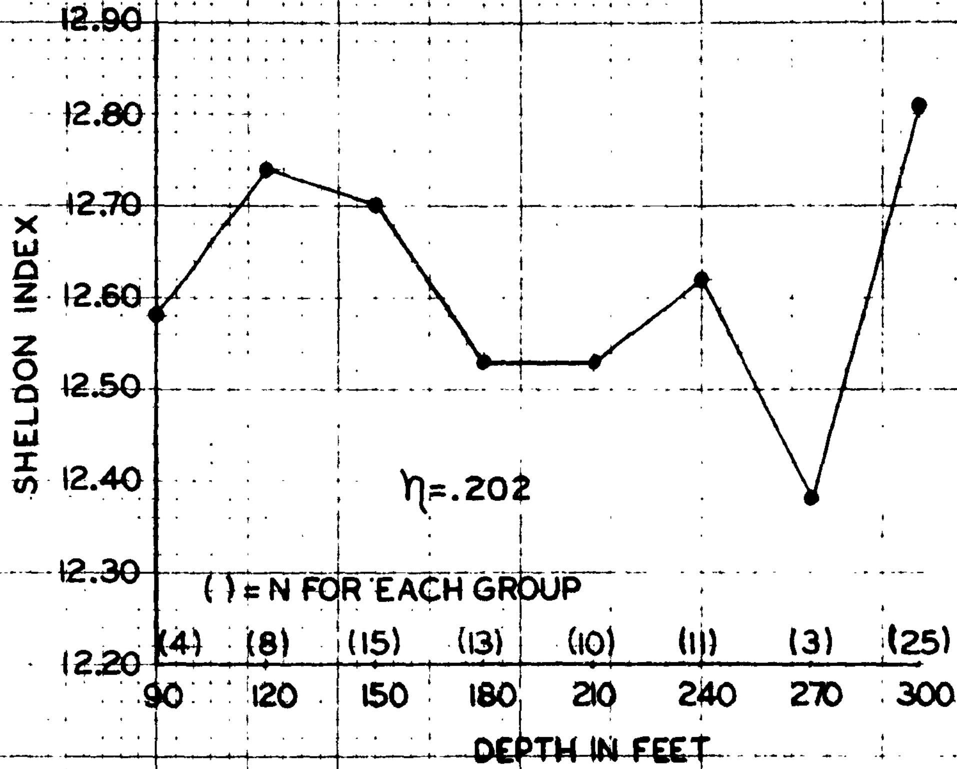
The hypothetical curve described by the work of Behnke was not supported by the present data. An eta coefficient of curvilinear relationships between the Sheldon index of divers who had incurred bends and the depths at which decompression sickness occurred failed to reach significance. The curve resulting from the present analysis, which appears in Figure 2, is essentially a straight line. Among the eight depths under consideration, the body types of the afflicted divers varied only slightly. This indicates that the probability of dissimilar body types contracting decompression sickness does not seem to vary as a function of depth of dive.

5. DISCUSSION

5.1 Age

5.1.1 Since age has consistently been an important factor in susceptibility to aviation bends, it was surprising that the data yielded mean ages for the various groups which were essentially the same for all groups. This finding can probably be attributed to a low exposure rate for the older men. Very few chief petty officers would be expected to be found in a position other than as a supervisor with limited diving responsibilities and the younger men, are therefore, disproportionately exposed. This would have the effect of restricting the age range of divers and, thereby, creating a homogeneous age group. That some factor is operating to restrict the age ranges is indicated by the smaller standard deviations found for the two bends groups.

5.1.2 Lundin (18) reported a failure to find any differences in nitrogen elimination which could be attributed to age. Considering the small number of subjects (N=13), his findings can not be adduced as sufficient evidence for confirmation of the present results.



EMPIRICALLY DERIVED CURVE RELATING BODY TYPE TO DEPTH OF DIVE IN WHICH EPISODE OF DECOMPRESSION SICKNESS OCCURRED.

FIGURE 2

5.2 Weight

5.2.1 The mean difference between the groups when weight was used as the criterion also failed to reach significance. A similar restriction of range in weight measurements as there was in age is apparent from the standard deviations. The standard deviation of the no-bends group was 22.86 pounds, while a standard deviation of 19.32 was found for the bends group and one of 15.00 for the bends-uncomplicated group.

5.2.2 In the case of weight, age may be the controlling factor. Since age is associated with weight and the ages were restricted, then weight is necessarily restricted. Although a difference between weight measurements has often been reported in studies of aviation bends, it has not been a consistent variable and has been generally considered a rather poor indicator of the degree of obesity.

5.3 Height

The differences between the groups' heights could have occurred by chance as indicated by the t-test. The same disadvantages associated with weight as an indicator of body build are inherent in height measurements as well.

5.4 Sheldon index

5.4.1 The obtained difference between the no-bends group and the bends group when the Sheldon index was employed, was significant beyond the 1% level of confidence. Although the obtained "t" value was statistically significant, the magnitude of the difference between these two groups would not allow for effective selection. The mean values of the groups would be represented by two six feet individuals, one weighing 187 pounds and the other, 182, with the heavier individual falling into the bends group. A difference of only five pounds could easily occur during day to day weight fluctuations. The representative values derived at the point of one standard deviation below the mean would, of course, be more disparate. In this instance, there would be a difference of ten pounds.

5.4.2 The difference between the no-bends groups and the uncomplicated bends groups on the Sheldon index was not significant. This finding casts more doubt upon the advisability of using the previous difference for a selection criteria.

5.5 General considerations of results on constitutional factors

5.5.1 It was expected that the difference between the bends and bends-uncomplicated groups would be greater than the difference between the no-bends group and the bends group. The bends group included a number of divers who were not necessarily prone to decompression sickness but may have contracted bends by accident or failure to follow proper safety precautions. Therefore, there was reason to expect some similarity between the bends and the no-bends groups. On the other hand, because there was apparently no reason other than individual susceptibility to account for the incidence of bends among the bends-uncomplicated group, this group was expected to be more dissimilar from the no-bends group. These expectations were not confirmed.

5.5.2 The results may have been affected by a lack of reliability, which has been found to be an important factor in measuring susceptibility to aviation bends. Generally, resistance to aviation bends has been measured by the incidence of bends after flights to altitude. One flight per subject has not been a reliable indicator and, consequently, the usual procedure has been to administer several flights to each subject. With several tests, chance fluctuations are more adequately controlled and only the "true" susceptibles remain.

5.5.3 Most of the divers in the present study reported only one incidence of bends. Since there was no way of determining if all of the subjects had been exposed to equally hazardous dives an equal number of times, reliability could have conceivably affected the results. The group of divers who had three or more cases of bends did, however, have a sufficient number of hazardous jobs to give a reliable index. Therefore, all of the subjects who contracted bends three or more times were analyzed separately. This multi-incident group did not differ significantly from the no-bends group on any of the variables. A mean age of 30.49 years, a mean weight of 170.59 pounds, and a Sheldon index of 12.62 were found.

5.5.4 A dissimilar etiology of aviation bends and diving bends could be the reason that the selection variables which were found to be successful in aviation bends are not applicable to diving. Evidence for a different etiology can be adduced from several sources. Piccard (22) has indicated that hyperbaric and hypobaric pressures lead to different bubble formation and bubble composition. Bubbles formed from hypobaric pressure are, although larger, fewer in number and are less likely to form. Jones (14) has noted that the rate of nitrogen elimination increases abruptly at 38000 feet which he attributes to the anoxic stimulus to circulation and thus an increase in nitrogen exchange. Age and fat could both detrimentally affect blood perfusion so that the older and more obese individuals would not benefit from the increased blood flow. Nitrogen saturation of the tissues is also different in diving and aviation bends. In diving the tissues are rarely completely saturated to the depth of exposure, while at altitude, they are always saturated unless pre-oxygenation has been completed prior to ascent. Consequently, different tissues may be involved in the formation of bubbles.

5.6 Depth and body type

5.6.1 The hypothesis concerning the influence of depth upon the type of body inflicted with bends relies upon a theory of gas diffusion. Accordingly, the body acts as a common reservoir for gas where gas is readily diffused from one tissue to another. If diffusion occurs in this manner, then the more obese persons should be protected from bends until the fatty tissues are completely saturated and, thus, would prevent the diffusion of gas (1,3). According to the results obtained from this study, however, this apparently does not occur. After shallow dives, where Behnke would expect that the time of exposure of the adipose tissue would not have permitted complete saturation, the body build of individuals who incurred decompression sickness was no different from those incurring bends after medium dives where Behnke would expect that the quantity of gas taken up by the tissues should have been much greater. Thus, the fat man does not seem to be protected from bends after short, shallow dives nor more susceptible after medium dives.

5.6.2 The results are more congruent with a theory of perfusion limited tissues. According to this concept, the gas exchange within tissues is not dependent upon the type of contiguous tissue, but instead the blood perfusion rate of the tissues and to a lesser degree the solubility of the tissues (5,14). Thus, bends could occur whenever the quantity of dissolved gas in the tissues exceeds the transport capability of the circulatory system without excess gas diffusing into other tissues. Thus, unsaturated adipose tissue could not act as a buffer to the tissues which, because of better circulation factors, may be supersaturated and eliminating gas more rapidly. Since the occurrence of bends would depend on the rate of blood transport and solubility, and since fat is poorly perfused and readily absorbs gas, the blood perfusion theory would predict greater susceptibility for the fat man at exposures where the fat is saturated (13,18,19).

5.7 Theoretical considerations

5.7.1 Although the present study contained shortcomings such as no control of frequency of diving or of comparable exposures, the data have enough veracity to indicate to the author that the role of adipose tissues in decompression sickness has been over-emphasized. It is unlikely that the failure to find differences between the bends and no-bends groups was due to distortion of the data alone. The data were based on a large number of cases where it would be logical to expect that any veritable differences in the factors considered would be apparent even with some distortion present. In an effort to elucidate the role of fat, experimental results will be discussed.

5.7.2 As the most convincing evidence of the blood perfusion theory, the nitrogen elimination studies conducted by Lundin and Behnke, and the radioactive inert gas elimination studies of Jones (13,18,19) have demonstrated that the rate of gas elimination can be adequately analyzed in terms of a multi-tissue theory of slowly and rapidly eliminating tissues. Generally, fat is considered to be the slowest tissue (5,14,18). However, the relationship between fat and time to eliminate is not clear cut and the existence of other poorly perfused, low capacity tissues has been suggested by Jones.

5.7.3 To ascertain the strength of the relationship between fat and time to eliminate nitrogen, a correlation coefficient was computed by the author from data presented by Lundin (18). A value of .78 was found between body weight and the time to eliminate nitrogen from what Lundin termed the slowest phase. Since the correlation was not perfect, other factors besides fat are required to account for all of the variance in nitrogen elimination from the slow phase.

5.7.4 Although Lundin's data do not show that fat is the only factor in nitrogen elimination, the relationship is strong enough to predict differences in susceptiblity to decompression sickness on the basis of fat content, even if measured by only weight. A possible explanation for the failure to find any differences in the present study could have been due to an incomplete saturation of the tissues as a result of the type of diving performed by the subjects. Thus, the differences in weight or body type were not manifested because they did not involve the slow, "fat" phase of elimination.

5.7.5 This was suggested by Jones and Behnke when they failed to find any differences between the rate of helium and nitrogen elimination (14). Since helium has a far lower oil solubility coefficient than nitrogen (ratio = 1:4.5), fat should retain appreciably less helium than nitrogen at any time during the exposure.

5.7.6 In view of this, the author made a search to find experiences with long saturation dives. An analysis by the author of data derived by Behnke (4) from studies of prolonged nitrogen saturation (12 hours at 40 feet) failed to demonstrate any consistent relationship between the incidence of bends among subjects and their fat content, as measured by specific gravity.

5.7.7 The seemingly equivocal findings between the influence of fat in the gas elimination studies and the studies of the relationships between fat and the incidence of bends may be more congruent than is apparent. None of the gas elimination studies induced bends. In the actual production of decompression sickness, the supersaturation of fatty tissues may be obscured by other factors which affect the formation of bubbles. Decompression sickness is intertwined with many factors, among them are perfusion, solubility, the mechanical effects of bubble formation, fatigue, etc. These factors should be investigated as thoroughly as the effects of obesity.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Constitutional factors

6.1.1 On the variables of age, height, and weight, no differences were found between divers who had incurred decompression sickness and those who did not.

6.1.2 When the Sheldon index was employed as the criterion, a significant difference was found between divers contracting decompression sickness and those who did not. The magnitude of the difference was, however, very small. Since this difference was not confirmed when complications of the dive were controlled nor when divers who contracted decompression sickness more than three times were compared with the no-bends group, the significant finding was probably spurious.

6.1.3 Since an adequate discrimination could not be obtained on any of the variables, none could be employed as selection criteria for bends-resistant divers.

6.2 Incidence of bends as a function of body type and depth of dive

No relationship between the depth of the dive and the body type of divers who incurred decompression sickness was found.

6.3 Explanation of findings

6.3.1 The failure to replicate the previous findings of aviation bends studies could be due to the nature of the data. Since the data were gathered from field activities, factors such as frequency of diving, a homogenous group, etc. could have been operating uncontrolled.

6.3.2 A more likely explanation for the difference is that the mechanism of aviation bends and diving bends is dissimilar.

6.4 <u>Recommendations for future projects</u>

6.4.1 The results obtained have indicated several areas in which further investigation is warranted. Although it is difficult to extricate the joint effects of factors controlling gas exchange and the production of bends, the results suggest that fat may not be a highly important variable in the actual production of bends. Other variables may play a much more important function in the onset of decompression sickness than does adipose tissue. Factors associated with blood perfusion seem to present a lucrative field for inclusion in future studies.

6.4.2 More conclusive results could be obtained if all subjects were subjected to sufficient stress to induce decompression sickness at a number of different exposure levels.

6.4.3 With the attempts to achieve greater depths and time in diving, the selection of bends-resistant divers will become increasingly important. The need for the requisite research is immediate.

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APPENDIX

Number, N - N refers to the number of subjects employed

Mean, M - The M is the average value for a group of measurements

Standard deviation, SD - The SD is a value which describes the amount of dispersion of measurements about the mean. A small SD would indicate that the measurements are closely grouped about the M.

t-test, "t" - The t-test is a statistical test to determine if the difference between two mean values could have more probably arisen by chance rather than as a result of actual differences.

Pearson Product Moment Correlation Coefficient, r - r is a single numerical value which indicates how closely two variables are related in a linear fashion. It does not signify causality, only association. The value of r may vary from +1.00 to -1.00, indicating a perfect positive and a perfect negative correlation, respectively. A value of zero would mean there was no relationship between the variables.

Eta correlation coefficient - The eta indicates the strength of association between variables having a curvilinear relationship. Its value corresponds approximately to r.

Significance - This is an expression of probability used to indicate the possibility of a chance finding. Generally, a 0.05 or a 0.01 level of significance are required to reject the hypothesis that the obtained values are due to chance rather than actual representations.